United States
Department of
Agriculture

Forest Service

**Southeastern Forest
Experiment Station**

Asheville, North Carolina

COWETA
Hydrologic Laboratory

A Guide to the Research Program

October 1984

Coweeta Hydrologic Laboratory
999 Coweeta Lab Road, Otto, NC 28763
(13 miles south of Franklin off U.S. 441)

Early in our earth's history, the first clouds formed and the first rains fell. Time and time again these same waters have fallen from the atmosphere upon the land, flowed into our streams and rivers and into the sea, and returned to the atmosphere to fall again.

This endless circulation is the hydrologic cycle, and its study is hydrology.

Hydrologists study the quantity of water. They investigate flood and drought. And they study the quality of water, its fitness for human, animal, and plant use.

Here at Coweeta in the Southern Appalachian Mountains, forest hydrologists are at work. The 5,400 acres of this site constitute a living hydrologic laboratory. Over the more than 50 years that this laboratory has operated, forest hydrologists have measured the amounts and timing of rainfall, evaporation, and streamflow in the forest. They can now describe the cycle and quality of water in an undisturbed forest.

But they can also describe the effect of disturbances to a natural forest upon the hydrologic cycle. These disturbances can be from nature itself, such as insect infestations or tree diseases. But more often, these disturbances are from man.

Man uses the forests for many purposes. He harvests its wood. He needs the water flowing from mountain streams for industry and home use. And his factories send particles into the atmosphere that fall upon the forests. The forest hydrologist studies the effect such disturbances have on the quantity, quality, and timing of water

On the forested slopes around you here at Coweeta, scientists have developed methods to predict accurately the effect of changes in the forest upon water production.

Why are changes in water production important to man? Any increase in streamflow means that a stream can supply water to more people. And because population is increasing each year, so too is man's need for water.

History of the Coweeta Site

Before the first white settlement in this area, the Cherokee Indian Nation inhabited the land. From 1848 to 1900, white settlers cultivated less than 200 acres of the basin, primarily along the main streams. After the Coweeta Valley was purchased by lumber companies in 1900, the land was logged. In 1918, the Forest Service bought the tract and in 1923 designated it part of the Nantahala National Forest.

The site was set aside as the Coweeta Experimental Forest in 1934, and almost immediately measurements of rainfall, streamflow, climate, and forest growth began. These have been continuously monitored since. The first laboratory buildings, roads, climatic stations, and stream measurement devices were built by the Civilian Conservation Corps.

In 1948, the site was renamed Coweeta Hydrologic Laboratory, the only Forest Service outdoor site to carry the "Laboratory" title.

As activities at Coweeta increased, new office space and a new laboratory for chemical analysis were added. Computer storage of data, begun in 1958, has been pivotal in analyzing the long-term records compiled here.

More recently, the Laboratory was selected by the National Science Foundation as one of 11 sites in the nation for the Long-Term Ecological Research program (LTER).

The Laboratory's commitment to sharing its research with scientists worldwide has been recognized by its inclusion in the International Biological Program, the International Hydrologic Decade, and UNESCO's Man and the Biosphere project.

In addition, Coweeta Hydrologic Laboratory has assumed an important role in the training of new scientists in many biological fields. Scientists and graduate students from many institutions and other government agencies conduct research projects here in cooperation with staff scientists.

The building you visit first at Coweeta was constructed in 1980 by Job Corpsmen. But since most of Coweeta consists of its outdoor living laboratory, you are invited to visit several of the accessible experimental sites. Because the roads are steep and narrow, please drive carefully and be prepared to share the right-of-way at all times.

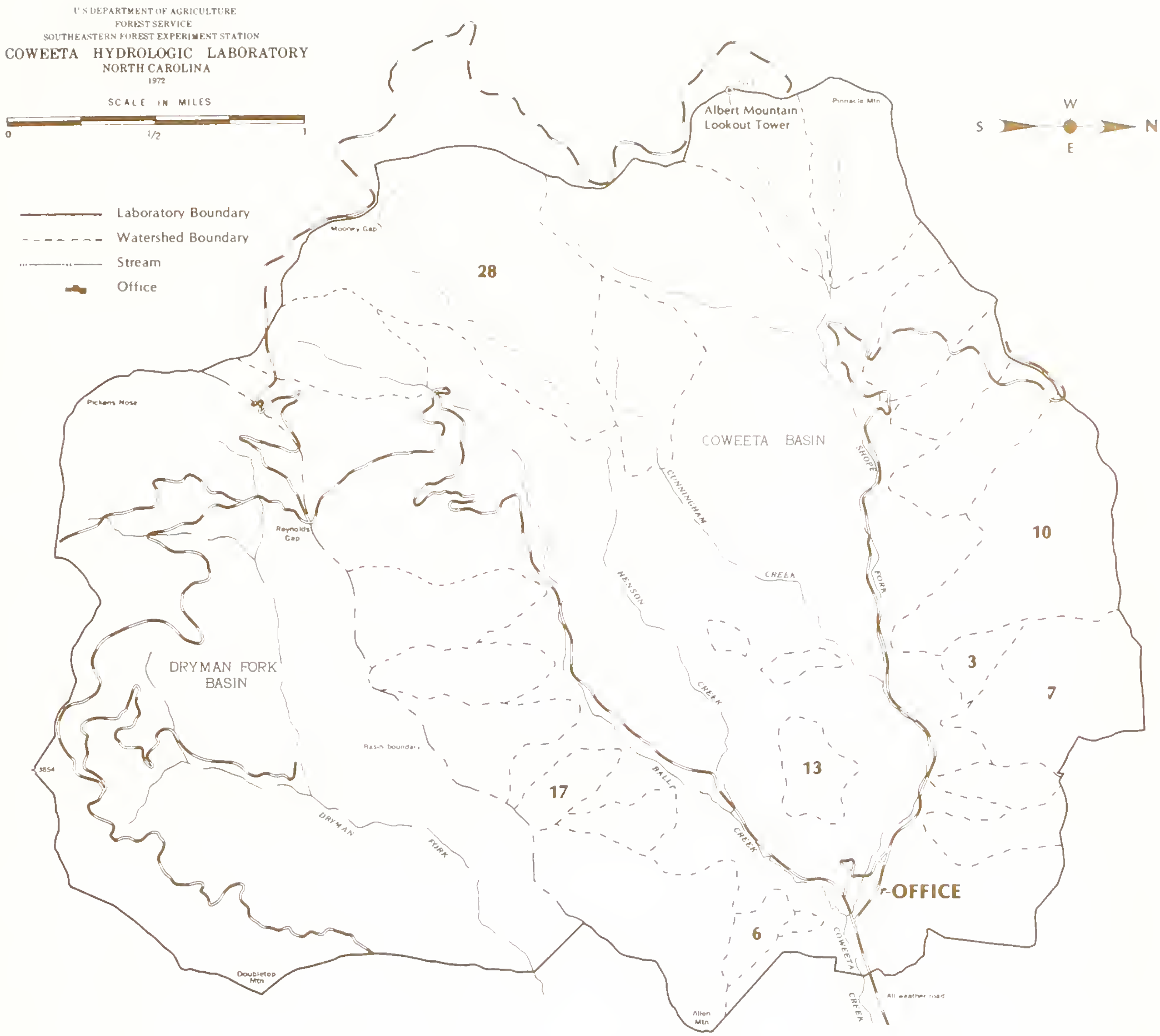
The Watersheds

The Coweeta basin is ideal for hydrologic research for several reasons. First, local rainfall is unusually plentiful—80 to 100 inches per year. Second, solid bedrock underlying the soils permits the hydrologist to account for most of the rainfall that enters the basin. Third, the valley contains numerous small **watersheds.**

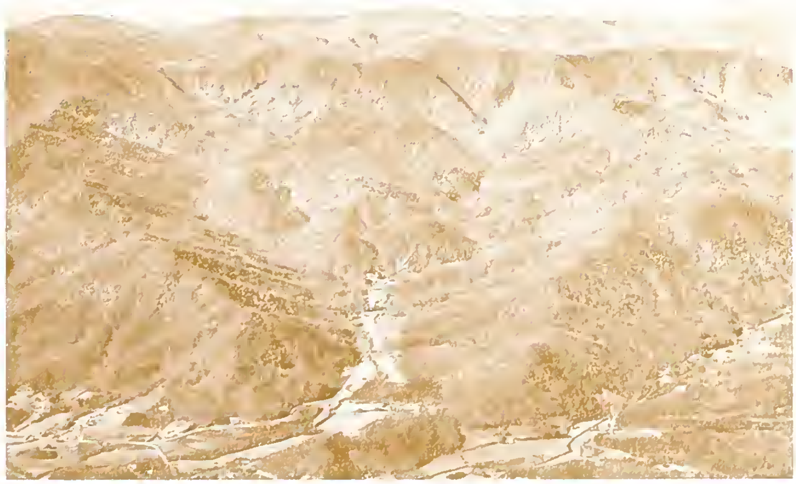
A watershed is a basin of sloping land surrounded by ridges and drained by a stream. Watersheds are natural units for research because the quantities of water flowing in their streams and the materials in the water are sensitive indicators of the success or failure of land management practices.

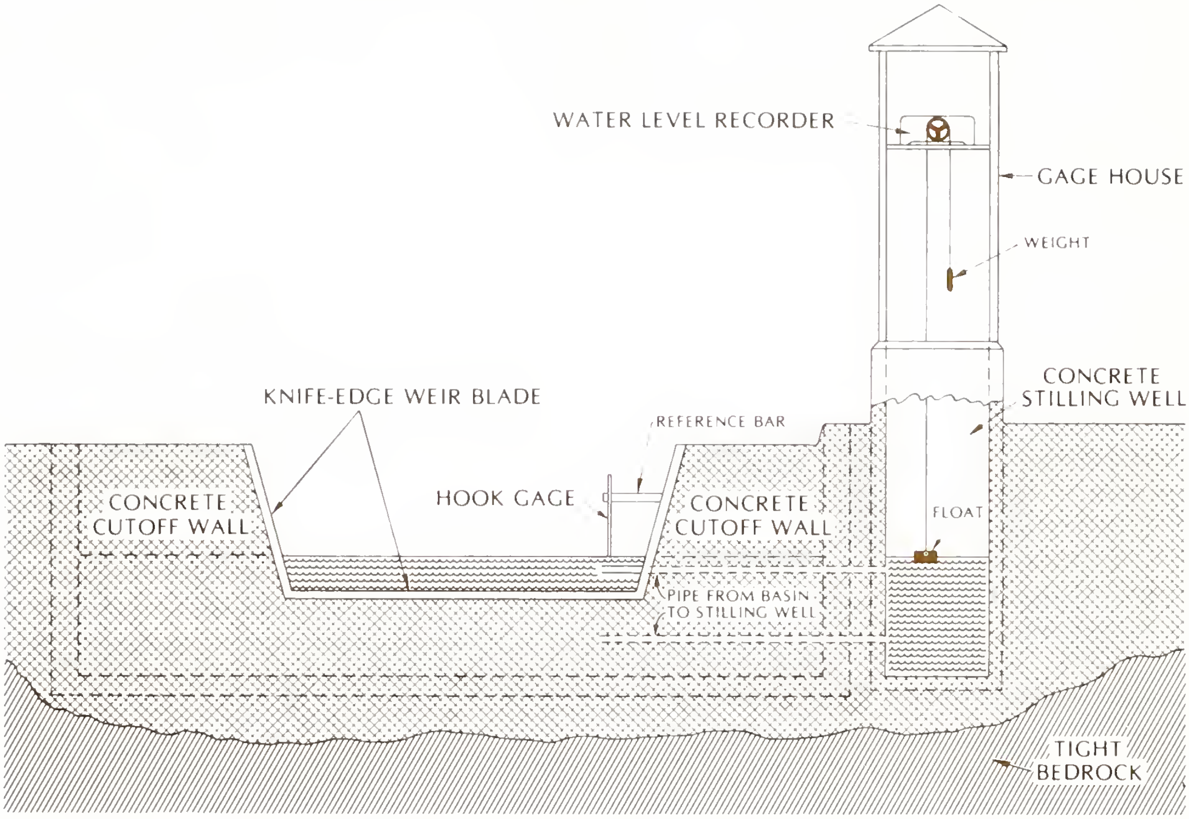
Many of the watersheds here are similar in size, climate, and vegetation. Before the vegetation on these watersheds was disturbed, streamflow characteristics were carefully related to rainfall patterns. When scientists intentionally disturb one watershed, they have two ways to determine the effects: comparison with conditions before disturbance on the same watershed, and comparison with an undisturbed watershed at the same time.

Each of the experimental watersheds has a weir in its stream to measure the flow of water. The weir is an accurate stream gaging station (example on page 4). The height of the water behind the weir blade is continuously monitored by automatic recorders. The heights, along with the characteristics of the opening of the weir, permit calculation of streamflow day and night, storm and sunshine, throughout the year. Silt that accumulates in the ponding basin behind the weir may also be measured. These measurements show how disturbances to the watershed change stream characteristics.



Coweeta Hydrologic Laboratory encompasses 5400 acres. The arrow in the photograph shows the office at the bottom of the valley. The roads are open to the public. Watersheds mentioned in this brochure are numbered on the map.





A weir, with its precisely constructed opening for the passage of water, is the heart of a stream gaging station.

The 6-foot rectangular weir on Watershed 8 measures stream and stormflow continuously.
A. knife-edge weir blade; B. flood flow section; C. bypass for carrying streamflow during repair or maintenance; D. plug for draining basin to measure silt accumulation; E. device for dampening wave action in ponding basin; F. level wall to kill velocity of water entering the ponding basin.

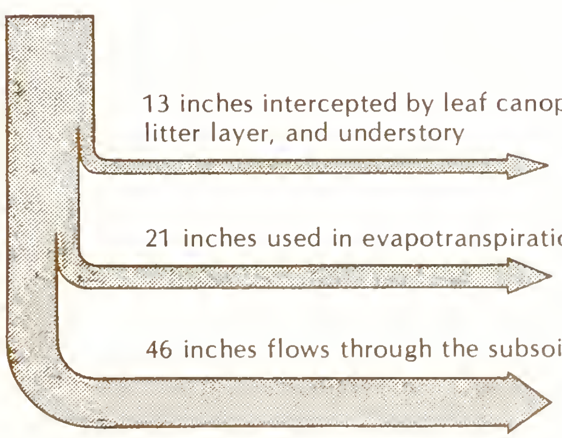
The Undisturbed Forest

A forested watershed does not receive rain in the same way as the street in front of your house. In the forest, rain first touches the leaves in the forest **canopy** above your head. Only when these leaves have become wet does the amount reaching the ground approach that falling in the open. That is why you can stand under a tree at the start of a heavy rain and be protected by a somewhat leaky forest umbrella.

Some of the water that passes through the forest canopy wets the leaves of the **understory**—the younger trees, rhododendron, and laurel beneath the canopy. Rain that passes through the various layers of vegetation and reaches the ground is called **throughfall.** That which evaporates from the leaves without reaching the ground is called canopy **interception loss.** Additional water is trapped by the **litter**—the blanket of dead leaves and twigs on the forest floor. At Coweeta, 13% of annual rainfall is lost through interception. Of the water that reaches the soil below the litter layer, about 30% is taken up by plant roots and used in the process called **transpiration.** The remainder, which is more than half the annual rainfall at Coweeta, moves beyond the tree roots, percolates through the deep subsoil, and reaches a stream.

Studies of the movement of rainfall through the undisturbed forest give scientists accurate baseline data prior to experimentation.

If rainfall is 80 inches



Hydrologic Activity in an Undisturbed Hardwood Forest

The Early Experiments

Scientists never doubted that farming on steep slopes and exploitative logging were destructive to soil and water. They needed to know the nature and extent of damage caused by such practices.

Mountain Farming and Grazing

In 1940 Watershed 3 was cleared, and corn was planted on 6 acres. Pasture grasses were planted on 7 acres, which were grazed in alternate years. Expecting large sediment runoff, the scientists designed a large debris basin and deep-notch weir to measure the erosion.

During the 14 years of study, corn yield declined even after commercial fertilizer was applied, and yield was ultimately insufficient to pay for the seed. Cattle trampled the pasture soil, reducing its ability to absorb water.

By the end of the 13th year, such conditions generated a 215-ton increase in silt in the ponding basin. The stream itself widened and deepened, and frequent floods overflowed the streambanks.

In 1941, control plots were established on Watershed 7; half of these were fenced and half were opened to unrestricted cattle grazing. Soil absorption of rain decreased significantly on the grazed plots. And at the end of the 8th grazing season, there was a sharp increase of sediment in streamflow.

As forage disappeared, the cattle were forced to browse on foliage of the hardwoods. Yellow-poplar growth declined 50%, and growth of other species also decreased.

These experiments demonstrated the damaging effects of sidehill farming and grazing, and such practices in the mountains were strongly discouraged.

Logging

Watershed 10 was opened to local practices of timber clearing between 1941 and 1948. Logging roads were located and constructed by traditional methods, horses were used to skid the logs downslope to loading decks, and trucks hauled the logs out of the forest. As expected, erosion from skid trails and roads was extensive.

Turbidity is a measure of the concentration of soil particles in stream water. In the undisturbed forest here, turbidity is about 4 parts per million; during the logging operation, turbidity averaged 94 parts per million, reaching an alarming 5,700 parts per million during one storm in 1947. And such pollution persisted long after logging was stopped.

These findings encouraged scientists to identify road construction and logging practices that would protect water quality.

Responsible Logging Practices

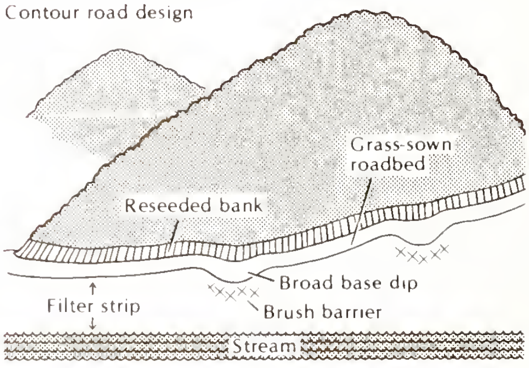
Road Construction

Coweeta scientists have developed road design standards for mountain forest land which have been adopted as best management practices by nearly all Eastern States. Key recommendations are the following:

1. Construct roads along the contour and avoid steep grades whenever possible.
2. Avoid the older road construction practice of building climbing roads beside streams.
3. Cross streams at right angles and install culverts or bridges.
4. Avoid ditching on the upper side of the road.
5. Break long slopes with gentle dips to trap and discharge water moving down the road. Place brush barriers at the runoff point.
6. Provide a minimum width of undisturbed vegetation, called a **filter strip,** between roads and streams.
7. Either cut banks vertically, or backslope and immediately seed them with grass.
8. Match the road surface to amount of use. When there will be little traffic, grass is economical and effective.

Coweeta researchers found that these construction techniques produce a low-cost, self-maintaining road network which allows timber harvest in steep mountain land with minimum damage to the water resource.

Contour road design



Broad dips minimize erosion on roadbeds and permit water discharge. Note that ditching should not be placed on the upper side of the road, and the road should follow the contour of the mountain where possible.

Timber Cutting

Erosion of soil and impairment of water quality in streams during logging operations are the result of disturbance to the soil litter layer while skidding logs and not from tree cutting itself. This concept has been demonstrated here in many studies.

In the late 1950s, an A-frame winch and boom were used on two sites to skid logs to the log deck. The A-frame cable lifted the larger, or butt, end of the tree off the soil and skidded it uphill a maximum of 600 feet to the deck. Rarely was more than one tree winched over the same trail.

In 1963, during clearcutting operations on Watershed 28, crawler tractors were used to winch logs in much the same way. Skidding logs across watercourses was prohibited, and tractors were restricted to roads or ridges to reduce disturbance adjacent to the stream.

In 1977, cable logging was demonstrated on Watershed 7. **Cable logging** is a method that suspends logs on heavy wire high above the forest floor, virtually avoids skid trails, and requires less road construction.

All three logging techniques minimized erosion and stream turbidity.

Water Yield Studies

How does a forest regulate streamflow? At the beginning of this century, some scientists thought that cutting a forest would reduce water production. Others speculated that a clearcut forest would erode quickly, producing more water, but water unusable for man's purposes.

This question was answered decisively by an experiment on Watershed 17. In 1941, this watershed was clearcut, leaving the felled trees in place to avoid disturbing the soil. From 1946 to 1953, all new growth was cut back.

Water yield increased 60% in the first year when each acre produced nearly a half million more gallons of water. Yet water quality remained high and flood levels were within normal limits. In fact, streamflow was doubled in the driest month—October—when streamflow is normally lowest.

This experiment demonstrated that clearcutting increases streamflow and need not increase erosion. Erosion occurs because of the way timber is removed. If soil and litter layers are not severely disturbed, clearcutting can increase man's supply of pure water.

The A-frame winch skids the logs uphill to the log deck (1957).

The yarder cable moves logs above the forest floor to the log deck (1977).

Corroborating Studies

Removing the understory, thinning, clearcutting in strips, and clearcutting the entire watershed increased water yields in proportion to the amount of vegetation cut. Effects on water quality were minimal.

Other studies showed that *northslope* cutting of mixed hardwoods generated over twice the increase in streamflow as *southslope* cutting. To explain this difference, scientists studied both the amounts of solar energy reaching these slopes and the percentage of vegetation cut. They developed equations that accurately predict increases in streamflow in the years after cutting. These equations are used by forest managers to forecast water yield from their treatment of the watershed.

Scientists also looked at the difference between water use by hardwood and pine forests. Hardwoods are **deciduous**; they lose their leaves in winter and only transpire water during the growing season. Pines intercept and transpire water throughout the year.

Two watersheds at Coweeta were cleared of hardwood and planted in white pine. Measurements revealed that an acre of white pine used 250,000 more gallons of water per year than the same area of hardwood. Converting a hardwood forest to pine clearly reduces streamflow.

Scientists also investigated other vegetation covers that might protect soil from erosion and increase water production. But they found that a fertilized cover of grass planted on Watershed 6 used nearly the same amount of water during the first few years as the hardwood forest it replaced. When fertilizing was discontinued and grass grew less vigorously, streamflow did increase. Thus the type of vegetation cover and its vigor affect water yield.

Multiple Use Land Management

High on the western ridge overlooking the Coweeta basin is the Appalachian Trail. This national hiking trail passes through Watershed 28, a multiresource forest management demonstration site.

The 356-acre watershed has several types of forest covers, sparkling streams, and many species of wildlife. Because of these features, the watershed was divided into compartments for the management of water, timber, wildlife, and recreational resources.

Permanent access to all parts of the watershed was the first priority of management operations. Careful road design protects soil and water resources, minimizes maintenance costs, and provides access for present and potential uses of the watershed.

In 1963, a yellow-poplar stand was thinned to stimulate growth of the best trees, and mature hardwood stands were clearcut to increase water yield, regenerate high-quality timber, and produce deer browse.

Roads for both timber operations were seeded. Roads that are still used are largely self-maintaining, while those retired from use can be reopened at little cost.

Trout habitat was improved by clearing the stream of debris and installing small fish dams. Clearings created by timber cutting offer hunters good views for sighting game. In addition, the young vegetation in these openings provides food for animals. Hikers on the Appalachian Trail overlook rapid forest reproduction of species such as red oak and black cherry in the clearcut compartments.

The increase in water yield that follows timber harvests is particularly important to managers of municipal watersheds. They learn here that water yield is increased in proportion to the percentage of timber cleared or thinned. In the first year after cutting, increase in streamflow on this watershed would have supplied the needs of well over 1,000 people. Water quality was unimpaired.

This experiment clearly demonstrates the opportunity for compatible management of a variety of forest resources.

Variable Source Area Studies

Streams at Coweeta flow year-round, even in dry years, and even from watersheds as small as 10 acres. Scientists wondered what sustains this flow in dry periods and asked the basic question of how water moves from the forest to the stream.

The deep soils here are capable of taking in rain at rates over 10 inches per hour. When there is plenty of litter on the forest floor to trap rainfall, storm water does not move over the top of the soil as surface runoff. Therefore, most water moves to streams solely below the surface, but what are the mechanics of this process?

To find out, scientists constructed a large soil model, a rectangular box filled with soil, on a natural mountain slope. The soil was soaked and covered to prevent evaporation.

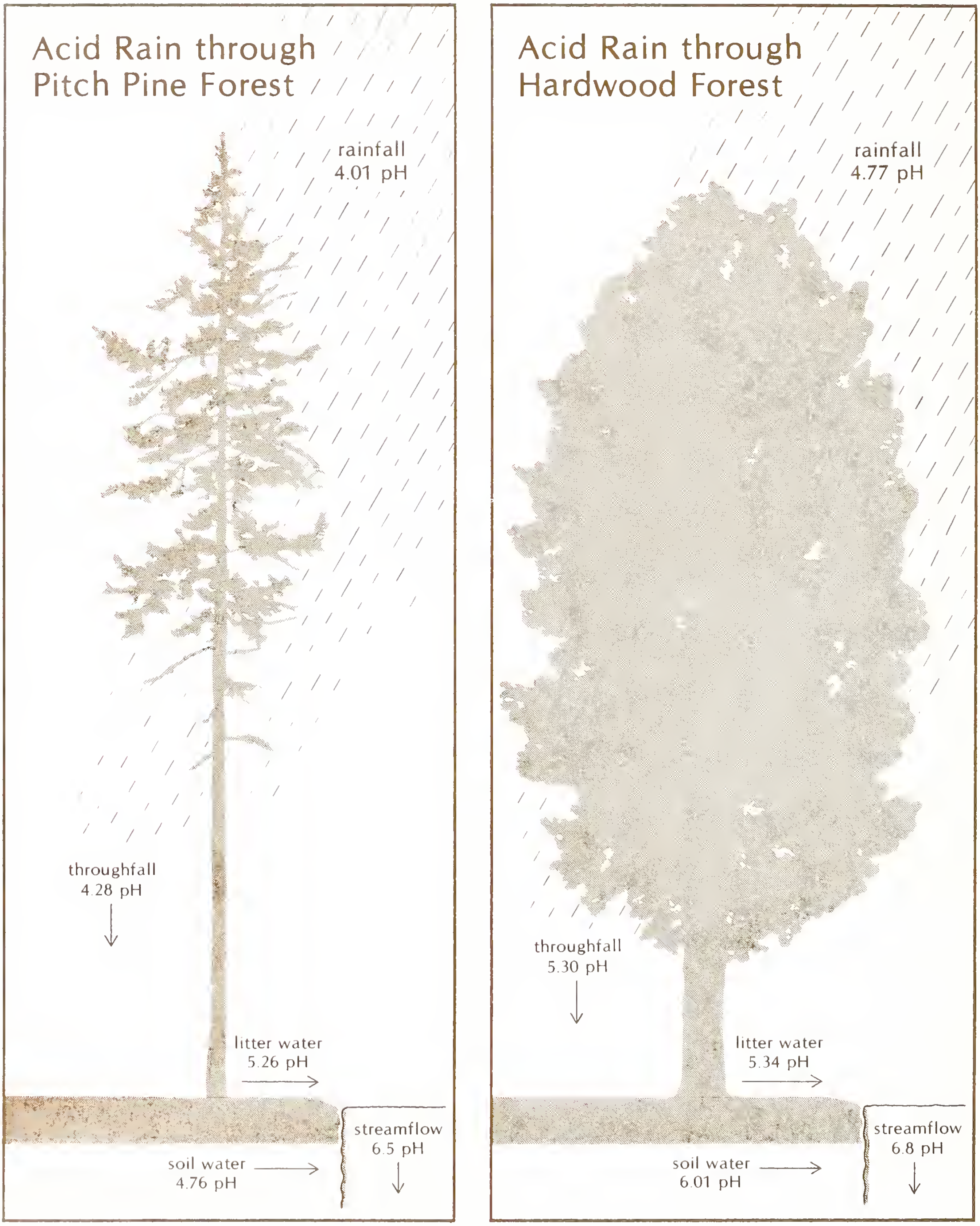
Water drained continuously from the model for 145 days without rewatering. In the first day and a half after soaking, drainage came from saturated waterflow near the base of the model. Later, however, water continued to flow from unsaturated soil. Scientists learned that water flows through unsaturated soil as individual molecules move downslope in response to the balance between gravity forces and soil moisture. Combined with deep soils, this hydraulic process maintains streamwater in the forest even in dry periods.

These concepts of subsurface soil flow have been widely used in computer models to simulate the response of streams to storms and dry periods.

Seeding roadbeds with grass stabilizes the road for many years without maintenance on Watershed 28 (1964).

The cover on the soil model has been thrown back to expose the soil. The barrel at the foot has an automatic flow recorder. Soil moisture and soil temperature measurements are also taken.

Log and stone dams create deep water shelter for native trout in this demonstration of multiple use land management on Watershed 28 (1963).



Acidity of rainfall has been continuously monitored in hardwood and pine forests at Coweeta since 1972. Variance in rain acidity is due to measurements taken from studies conducted at different times.

Ecosystem Studies

The same characteristics that recommend the Coweeta watersheds for hydrologic research also recommend them for studies of ecosystem chemistry. Input of particles from the atmosphere and losses in streamflow can be carefully monitored. Some of these chemicals are nutrients, beneficial to forests. Others, such as sulfur, aluminum, and lead, may be harmful.

Precipitation samplers collect these particles from the atmosphere, while soil and water chemical analyses reveal their presence in the forest itself. The balance sheet of each material is called its **budget.** Coweeta researchers are determining what budgets produce a healthy forest and how these budgets are changed by forest management activities.

Another important study looks at acid rain, which affects soil and aquatic life, impairs water quality, and corrodes stone and metal. The second longest continuous forest study of acid rain in the East began here in 1972.

This study documents that local forests thus far have been able to neutralize the effects of acid rainfall. They are doing so by accumulating sulfur in the soil at a rate of 8 to 10 pounds per acre per year. Soil bacteria and fungi transform sulfates to organic sulfur, and soil particles also absorb sulfate. But the capacity of the ecosystem to continue this process is unknown.

Research is also underway on bacteria in the soil which convert nitrogen from the atmosphere to nitrate, a form plants need to survive. Other bacteria, called **denitrifiers,** convert nitrate back to nitrogen gas and release it to the atmosphere. Early findings suggest that wet soil loses more nitrogen than dry soil and that more nitrogen is fixed in the soil in forest openings created by cutting than in mature forests.

Scientists are also studying the effects of herbicides and pesticides on water quality. There is little leaching of such chemicals into Coweeta's streams when they are applied away from stream banks.

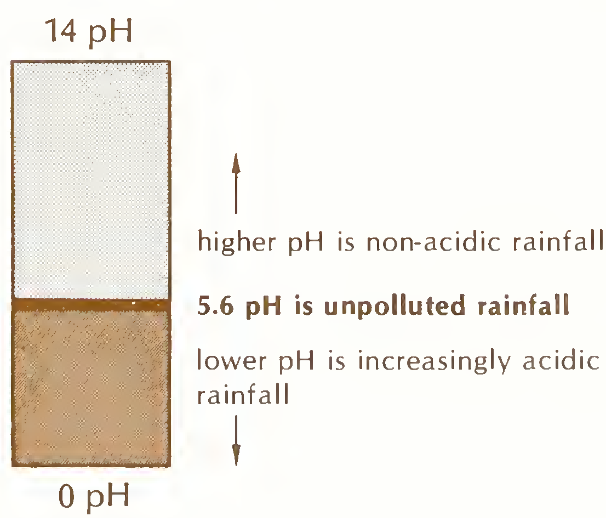
Insect Studies

Insect populations on land and in streams are important regulators of nutrient movement through the ecosystem. Therefore, following the logging experiment on Watershed 7, scientists examined the woody material and sediment that reached the streams and how this material affected the insect larvae that feed on stream debris.

Such organisms, including the larvae of mayflies, stoneflies, water beetles, and caddisflies, feed by a variety of methods. Leaf fall was greatly reduced the first year following clearcutting operations. Populations of stoneflies, which shred leaves, declined dramatically. Yet numbers of mayflies, that feed by gathering organic matter in the stream, increased.

In another study, scientists are looking at insects that live and feed in the tree canopy. In addition to determining what and how much they eat from year to year, the study is relating insect population to changes in rainfall, temperature, leaf chemistry, and streamflow.

Such continuing investigations are part of Coweeta's commitment to study forest ecology, the interaction between organisms and their environment.



The pH level is measured on a scale from 0 - 14. Each change is calulated in logarithms (1=10X).

This brochure was prepared in a cooperative project
between Western Carolina University and the
Coweeta Hydrologic Laboratory, SEFES

The first goal of research at the Coweeta Hydrologic Laboratory was to define the characteristics of the soil, water, and climate of forested mountain land in the Southern Appalachians. This goal was achieved.

From there, scientists moved ahead to demonstrate the damages that result from traditional mountain farming, road building, and logging. They then developed road building and logging practices that make timber cutting and clean water production compatible on steep mountain slopes.

Research at Coweeta now focuses on two of the most important problems facing the world community today: preservation of forest soil fertility and estimation of effects of atmospheric pollutants. Current investigations trace nutrient flows through the forest and determine reactions of the ecosystem to acid rain and deposits of particles from the atmosphere.

As man's needs for pure water and productive soil increase, the concepts being developed here must be applied throughout the world. Research results have been communicated in more than 500 papers based on studies here. In addition, visitors from across our nation and the world come here to participate in and observe Coweeta's continuing research.

Studies here show that man can improve or sabotage the hydrologic cycle. Scientists at the Coweeta Hydrologic Laboratory are helping society to make informed choices.